2007 DOE Hydrogen Program

Hydrogen Generation from Biomass-Derived Carbohydrates via Aqueous-Phase Reforming Process

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This presentation does not contain any proprietary or confidential information

Project ID #
PDP8

Overview

Timeline

- Start – Sept 2005
- Finish – Aug 2008 (Tentative)
- 20 % complete

Budget

- Total project funding
  - DOE share -1,942 K
  - Contractor share - 679 K
- Funding received to date
  - 369 K DOE
- Funding Reduction in FY06 resulted in limiting work to catalyst development

Barriers

- Feedstock Cost, Reformer Capital Cost, Operations Cost, and GHG emissions
- Feedstock Cost Reduction
  - 2012 Feedstock Cost Contribution $2.10/gge
  - 2017 Feedstock Cost Contribution $1.55/gge
- By 2012, reduce H_2 costs to $3.80/gge
  - Overall Efficiency 72%
- By 2017, reduce H_2 cost to <$3.00/gge

Partners

- ADM
- University of Wisconsin

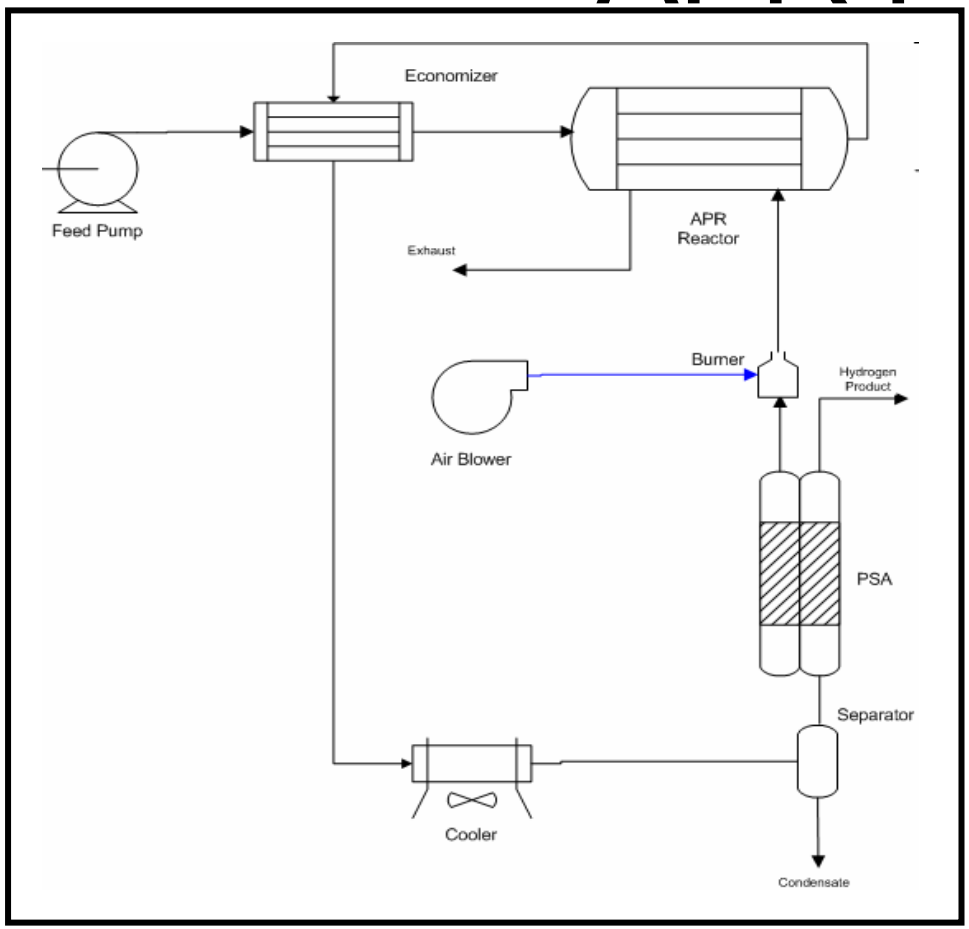
Objectives

Overall	• Design a generating system that uses low cost sugars or sugar alcohols that can meet the DOE H_2 cost target of $2 to 3/gge for 2017. • Fabricate and operate an integrated 10 kg of H_2/day generating system.
2006	• Limited scope of work for 2006 due to funding cutbacks. • Develop APR catalyst, reaction conditions, and reactor suitable for converting glucose to hydrogen.

Objectives (cont)

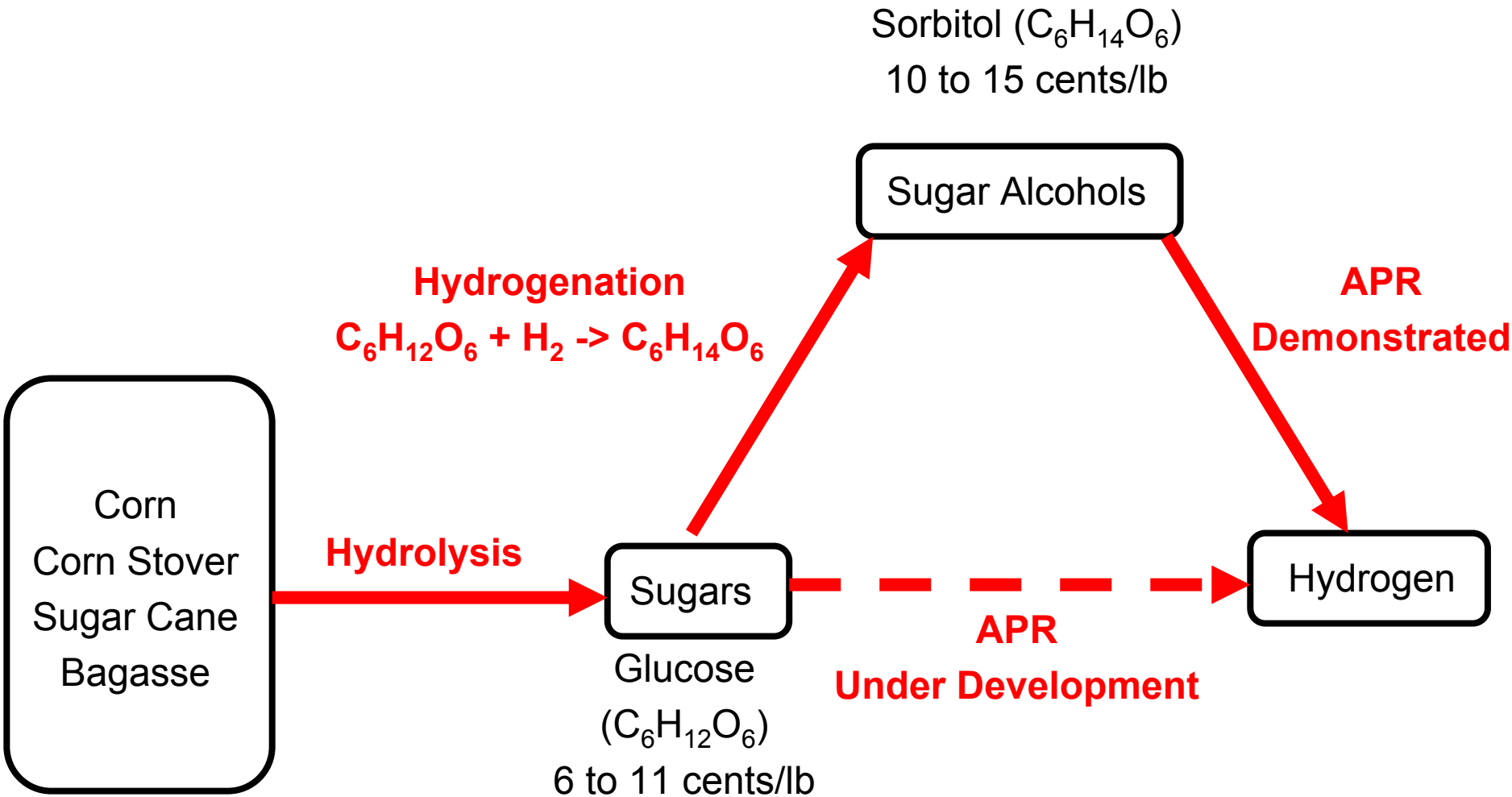
2007	• Virent will continue to investigate catalyst, reaction conditions, and reactor suitable for converting low cost sugars to hydrogen • Calculate the thermal efficiency and economics of the APR system utilizing different feedstocks (low cost sugars, glucose, sugar alcohols) • Compare results of techno-economic analysis with DOE Hydrogen Programs Goals • Make a Go No-Go decision on moving forward to the design and construction of a 10 kg H2/day demonstration system with the preferred feedstock. • Design of 10 kg H_2/day demonstration system
2008	• Fabrication of 10 kg H_2/day system • Startup and operation of 10 kg H2/day system • Analysis of 10 kg H2/day system

Hydrogen Production using the APR Process

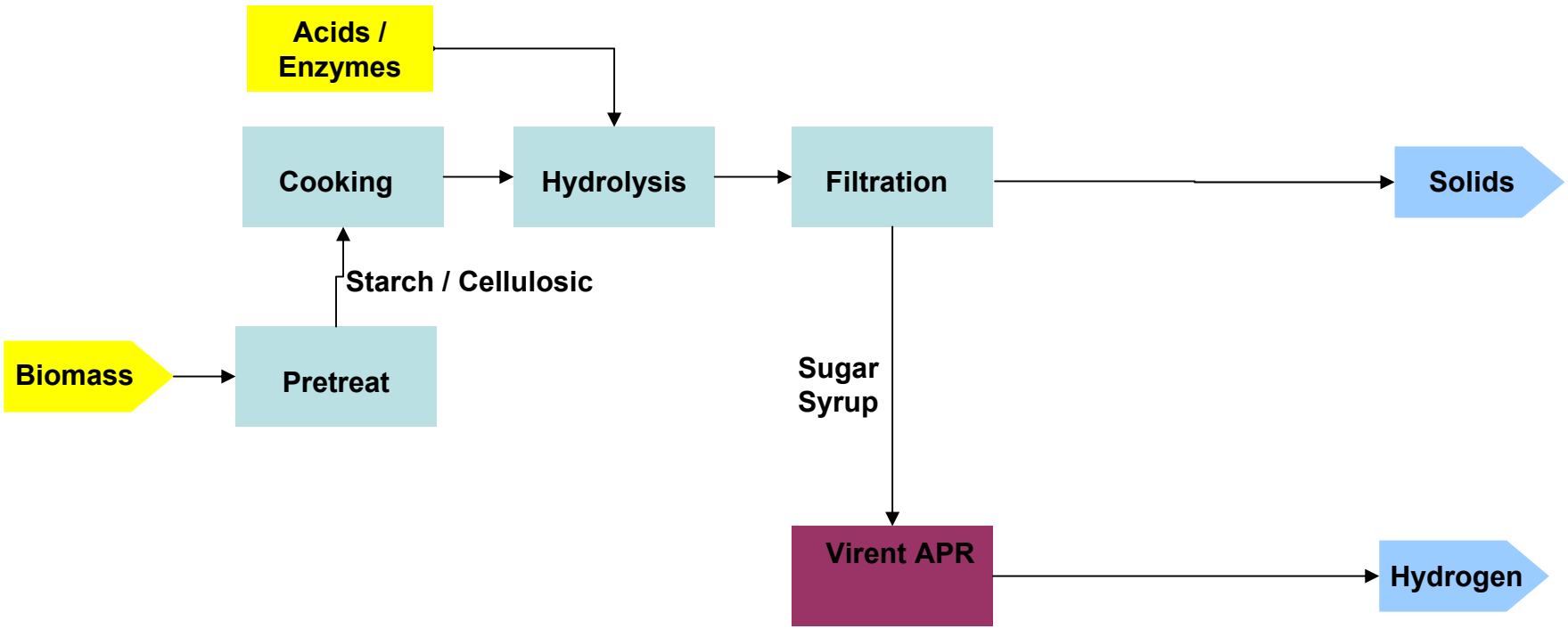


- Simple Catalytic Process
  - No Water Gas Shift
  - No Steam System
  - No Gas Compressor
  - No Desulphurizer
- Energy Efficient
- Scalable
- Feedstock Flexible

Approach


Sorbitol ($C_6H_{14}O_6$)
10 to 15 cents/lb
Sugar Alcohols
Hydrogenation
$C_6H_{12}O_6 + H_2 \rightarrow C_6H_{14}O_6$
APR
Demonstrated
Corn
Corn Stover
Sugar Cane
Bagasse
Hydrolysis
Sugars
Glucose
($C_6H_{12}O_6$)
6 to 11 cents/lb
APR
Under Development
Hydrogen

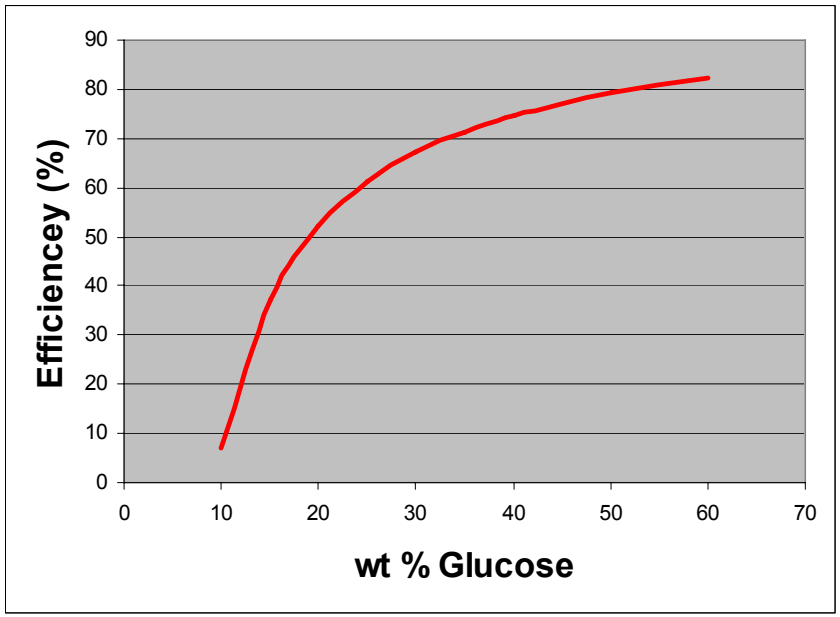
Biomass to Hydrogen via the APR Process

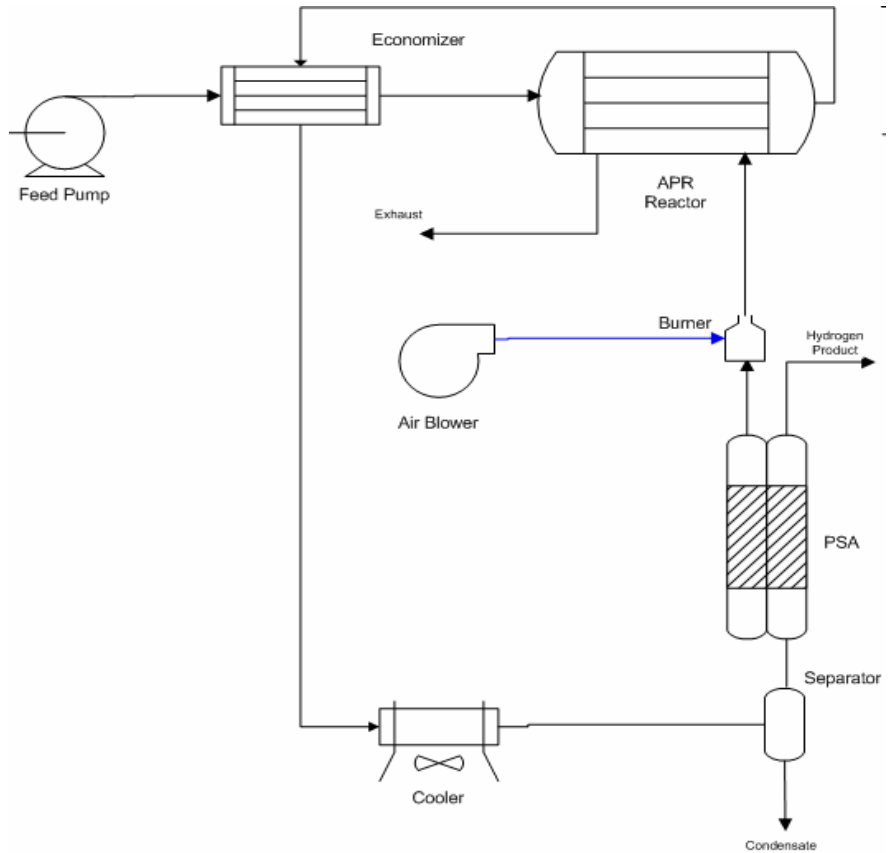


Technical Accomplishments/ Progress/Results

- Initiated project in September 2005
- ADM provided glucose samples for processing.
- Investigating catalyst and conditions for operations with high concentrations of sorbitol
- Investigating catalyst and conditions for operation with high concentrations of glucose
- Virent funded project to convert glycerol to hydrogen
  - Proved Catalyst Lifetime of greater than a year
  - Tested First Generation Reactor System
  - Designed and Constructed Second Generation Reactor System

Effects of Feed Concentration





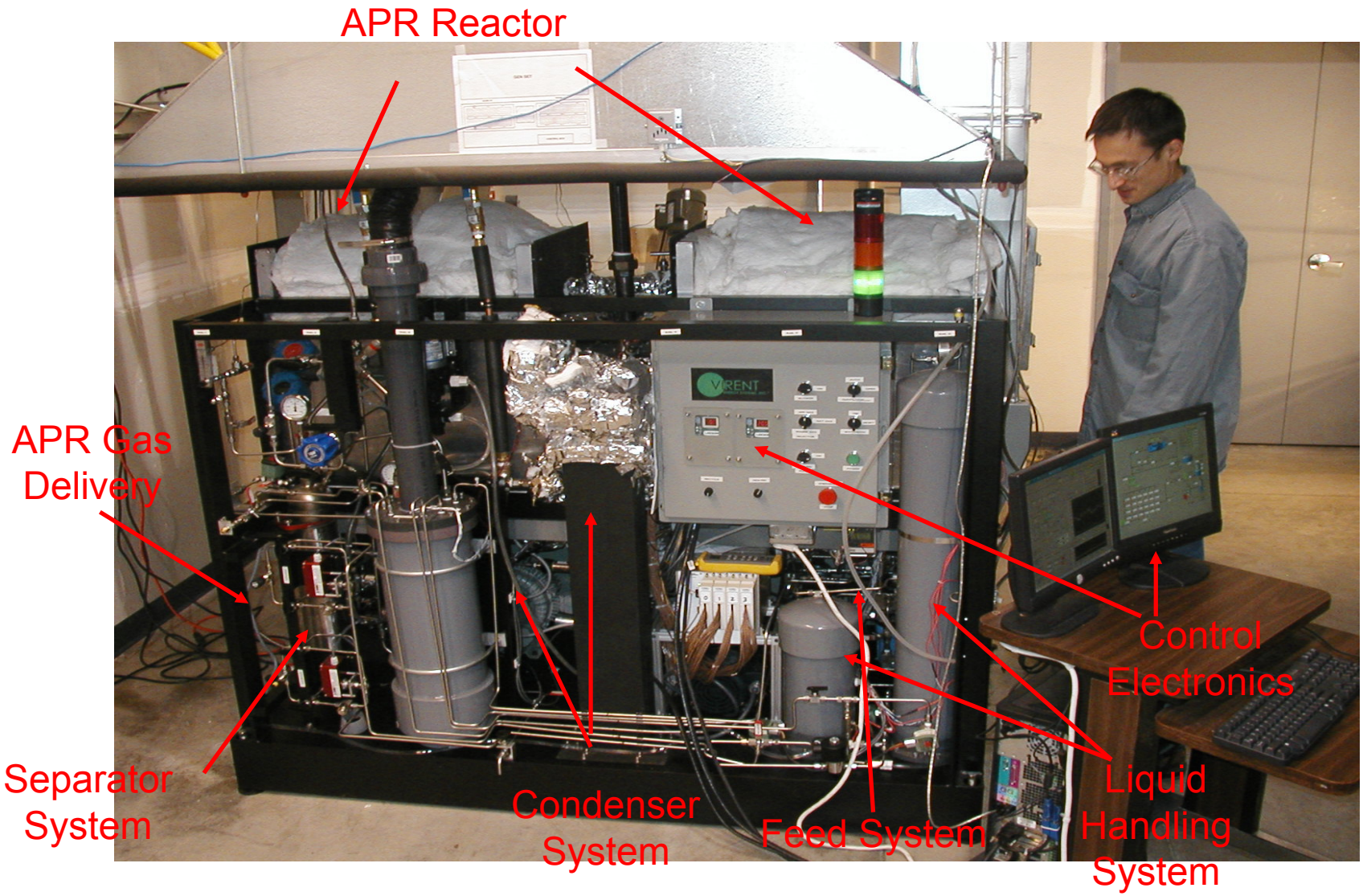
- System Efficiency
  - Combustion of Hydrogen for Process Energy Required
  - Higher Feedstock Concentrations Reduce Heating Requirements

Reforming of Glucose

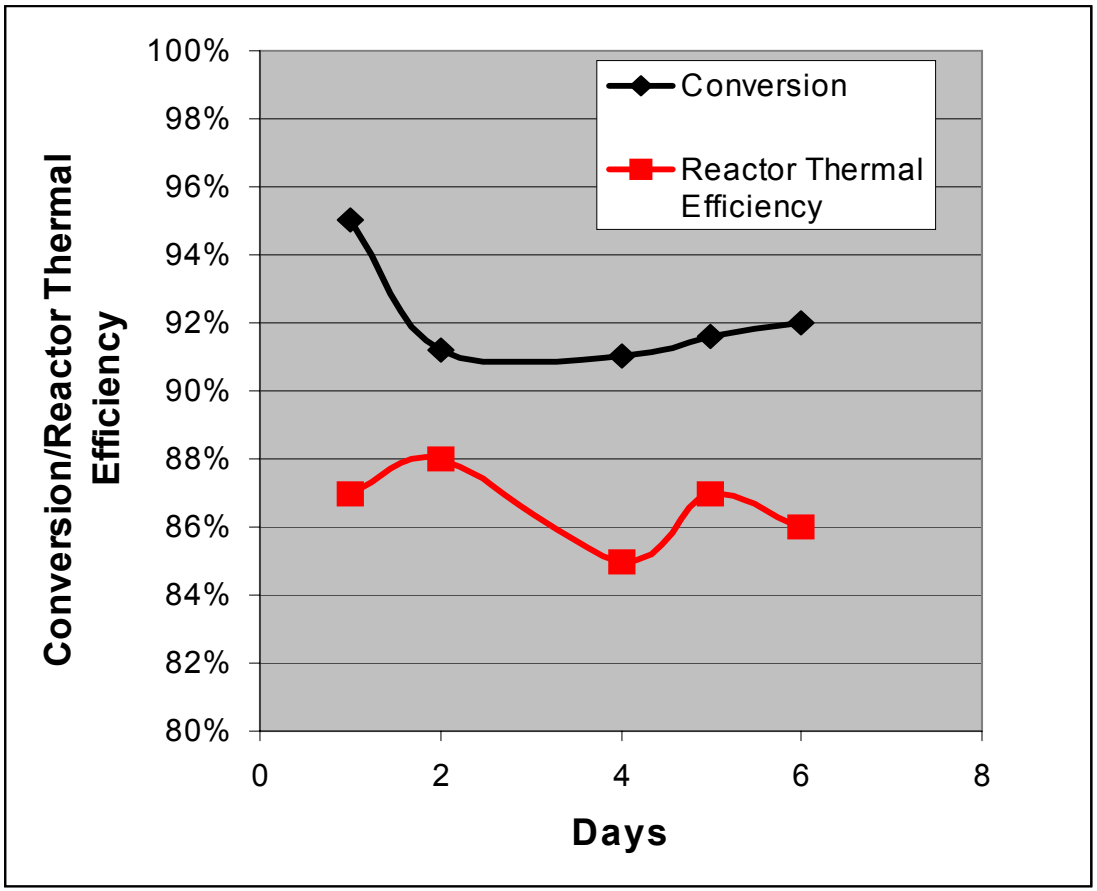
Date		Apr-04	Sep-05	Jan-06
Feedstock	30% Sorbitol	3% Glucose	30% Glucose	30% Glucose
WHSV	2.0 /h	0.897 /h	0.996 /h	2.1 /h
Reactor				
Temperature	240 °C	230 °C	240 °C	240 °C
Pressure	500 psig	430 psig	500 psig	600 psig
Conversion	100%	73%	100%	100%
Conversion to Gas	75%	14%	58%	36%
H2 Selectivity	72%	33%	23%	58%
Watt H2/gram	4.2	0.12	0.39	0.91
Watt Alkane/Gram	2.1	0.03	1.26	0.73

WHSV – gram of oxygenated compound per gram of catalyst per h

Green Energy Machine (GEM)



APR Reactor Performance



Single Pass Conversion

1.8 WHSV
based on Glycerol

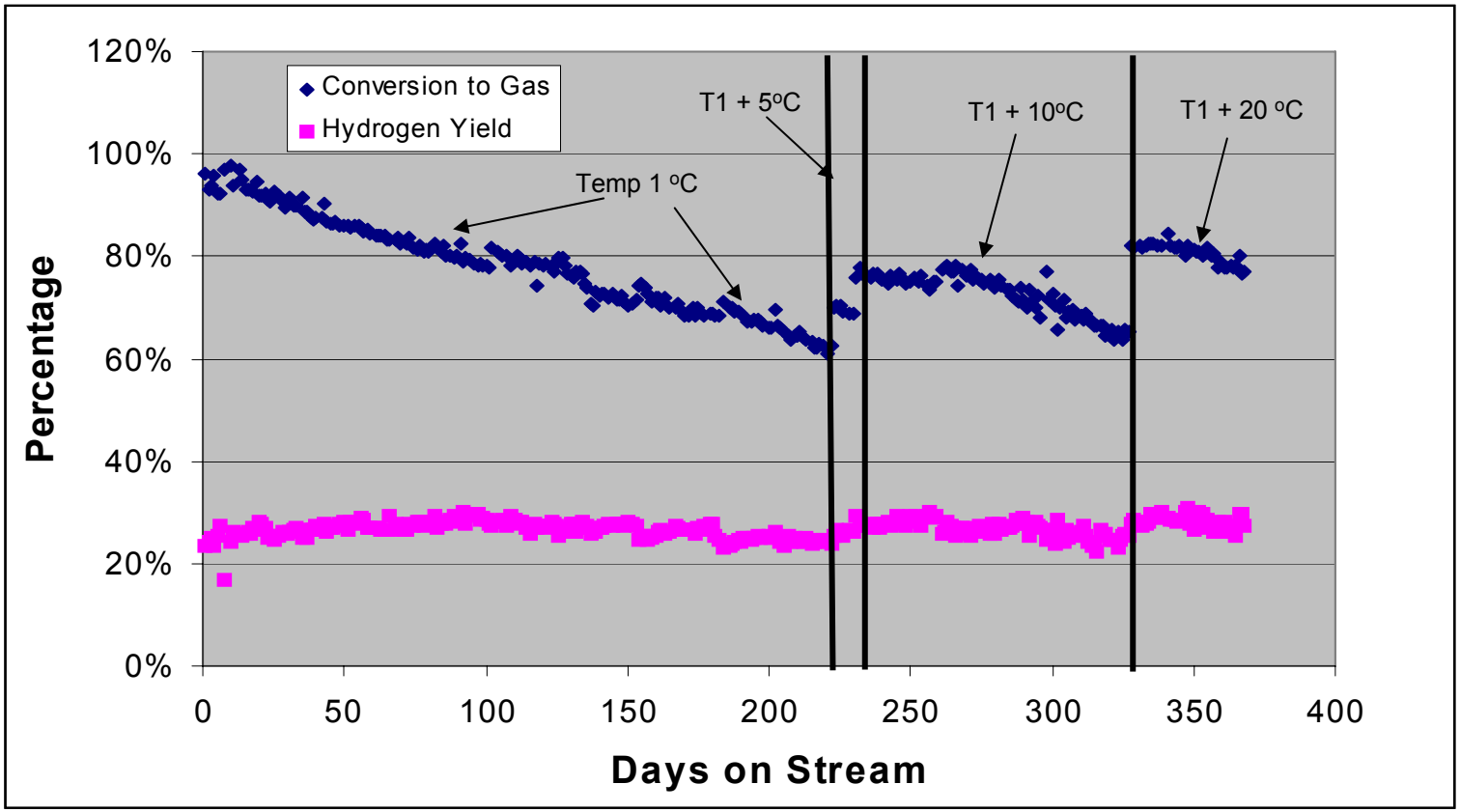
Reactor Thermal Efficiency

$$100 \times \left(1.0 - \frac{\text{Process Energy}}{\text{Generated Energy}}\right)$$

Process Thermal Efficiency
78.5 % of LHV of Feed

GEM Catalyst Lifetime Testing

13 months of Continuous operation



- 50 wt% Glycerol In water
- First Generation Catalyst
- One pass operation
- Very stable H_2 production
- Temperature can be raised to keep conversion high

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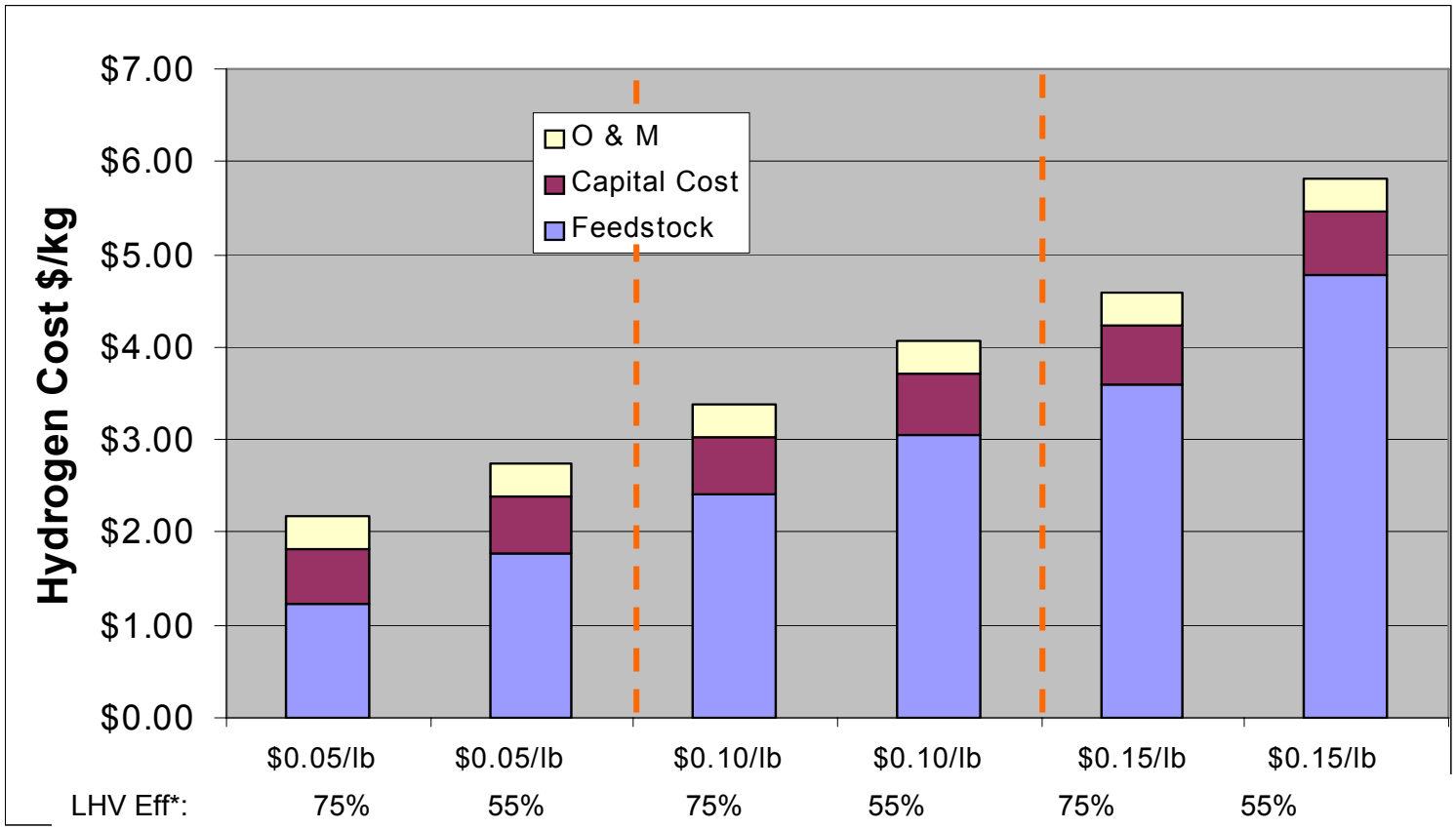
APR Outlet Gas Composition

Glycerol Feedstock

	SNG Catalyst Vol. %, Dry	H2 Catalyst Vol. %, Dry
Hydrogen	35%	60%
Methane	8%	7.5%
Ethane	12%	1.5%
Propane	5%	0.5%
CO2	40%	30.5%

Hydrogen Pilot Plant

Projected Cost of Hydrogen Using the BioForming Process



1500 Kg/day H_2, 10% ROI, 10 Year Project Life, Glycerol Feed

Capital Cost Includes APR PSA

Current Performance 55% LHV*

Projected Performance 75% LHV*

**LHV Eff: LHV of hydrogen exit PSA / LHV of Feed Glycerol*

Future Work

- Worked Planned for 2007

  - Develop APR catalyst and reactor that converts glucose to hydrogen.
  - Develop APR catalyst and reactor that effectively converts sugar alcohols to hydrogen.
  - Investigate hydrogenation technologies that convert both monosaccharides and polysaccharides to sugar alcohols
  - Investigate the integration of the hydrogenation technology with the APR technology.
  - Calculate the thermal efficiency and economics of the baseline APR system utilizing sugars or sugar alcohols as the feedstock.
  - Evaluate the baseline APR system against US Hydrogen program goals and determine whether to proceed to development of the demonstration system.

Future Work beyond 2007

- Develop the detail design of the demonstration APR hydrogen generation system (10 kg/day).
- Fabrication of the integrated hydrogen generation system.
- Evaluate APR hydrogen generation system performance against US Hydrogen program goals.

Summary

- Initiated Project in September 2005 with limited funding.
- Initial work with higher concentrations of glucose shows promise.
- Virent has already built and operate a 6 NM^3/h Alpha Unit utilizing glycerol as a feedstock.
- Virent will soon be starting up a second generation reactor system for generation of hydrogen from glycerol
- Will continue work with sugars as funding is available.